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ABSTRACT

One area explored in the second (in-depth) phase of the Learning in Science Project was "children's science," defined as views of the world and the meanings for words that children have and bring with them to science lessons. The investigation reported focuses on students' thinking regarding their views on particles and particle behavior. Students (N=41) were individually interviewed while they observed four events: a burning candle; the neutralization of an acid; the precipitation of lead chloride; and the explosive oxidation of magnesium. During the data gathering procedure (interview-about-events), students described what they saw happening and explained what happened. Selected student responses for each of these four events are presented and discussed. Among the findings reported are those indicating that a significant percentage of students: do not appreciate the basic particulate structure of all matter; are confused by the word "particle" with its multiple meanings, and do not understand the words "atom" or "molecule" in a scientific sense; do not consider that weight (or particles) are necessarily conserved in chemical reactions; and prefer to talk about what is observable rather than talking about abstract molecular models of what is happening. (Additional examples of children's use of everyday language, human-centered viewpoint and attribution of human characteristics to inanimate objects are provided in an appendix). (JN)

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# LEARNING IN SCIENCE PROJECT

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# PARTICLES

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WORKING PAPER No. 18

In our view successful science teaching requires an appreciation not only of the scientists' view of the world, but also an appreciation of the language, the beliefs and the expectations which children bring with them to science classes. This working paper has developed from a study carried out in the in-depth phase of the Learning in Science Project and is one of a series of papers which explores aspects of Children's Science (see Working Paper No. 14). It is our hope that these papers portray children's views of the world and meanings for words in a way which will be useful to teachers and to curriculum developers.

In the action-research phase of the project it is our intention to attempt to build practical and useful teaching strategies based on the findings of the in-depth phase of the project. For this reason we are actively seeking comments on the findings we have detailed, and seeking information on the variety of ways teachers develop ideas associated with the topic under focus in this paper.

We would be grateful if comment and/or information could be forwarded to

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# PARTICLES

A working paper of the Learning in Science Project

John Happs

October, 1980

## INTRODUCTION

This investigation (see also PHYSICAL CHANGE) attempts to focus on students' thinking with regard to their views of particles and particle behaviour, in the context of chemical change. Attention was brought to bear on how pupils visualize atoms and molecules and how they relate these to the term 'particle' and to chemical reactions. In some ways this investigation differs from many of our other studies. Here our focus of attention was less on children's science - those views of everyday phenomena that children have before formal teaching - and more on students' views of some scientific phenomena and scientific models found in chemistry.[1] This paper summarizes discussions with pupils about four particular events - a burning candle, the neutralization of an acid, the precipitation of lead chloride and the explosive oxidation of magnesium. These events involved situations which were both familiar, e.g. burning candle, and unfamiliar to the pupils, in terms of experiences outside the science laboratory. It is acknowledged that we did not expect most children, prior to the age of 14 - 15 years, to have scientific views about the reaction mechanisms, yet it was considered useful to explore the existing views that children have. These views may also permeate into the thinking of older students.

A total of 41 students were individually interviewed (3 x S4, 1 x F1, 5 x F2, 7 x F3, 9 x F4, 5 x F5, 3 x F6, 6 x F7, 2 x T)[2] from 6 co-educational schools and one Teachers College. Students were selected by their science teachers who were asked to choose children of "average scientific ability".[3]

During the interviews students were asked to describe what they observed and then explanation of phenomena was sought in terms of the student's own ideas. It was emphasized that what was looked for was the students' own explanations

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[1] Some examples of children's science that did emerge are given in the Appendix.

[2] S4 = Standard 4 (10 year olds); F1-7 = Form 1-7 (11 - 17 year olds); T = Teachers College students.

[3] We consider that children were average to slightly above average in most cases.

and viewpoints. As far as possible, questions were phrased to allow the discussion to centre about particle behaviour, should the students hold such views.

Every student was invited to participate in each event, and in this way situations were developed which allowed a 'hands-on' approach with students actually manipulating the materials rather than being spectators. This approach not only increased the students' involvement in each event but also tended to establish a more relaxed atmosphere.

Each event will now be considered in turn.

## EVENT 1: A BURNING CANDLE

Students were presented with a candle held in a glass container and a box of matches, and invited to light the candle. There followed a fixed sequence of open-ended questions which were supplemented by other questions directed towards aspects of the burning candle. The opportunity was provided for students to respond in terms of particle behaviour.

### (a) The wax

The initial questions in the interview attempted to ascertain whether, or not, children envisaged wax as consisting of particles and if they considered movement of these particles in the solid wax and/or in the molten wax.

When asked what the tiniest bit in the wax was like, 13 students (1 x S4, 3 x F3, 3 x F4, 1 x F5, 2 x F6, 1 x F7, 2 x T) included the word 'particle' in their response. Others appeared to have particulate ideas and talked about 'grains' (1 x S4, 1 x F1); 'crumbs' (1 x F3); 'the little bits of matter of which it is made up' (1 x S4, 1 x F4); 'cells' (1 x F4); and 'atoms' (1 x S4, 2 x F3, 1 x F4, 3 x F7). The remaining 15 students gave responses which indicated no real appreciation of a particulate nature for the wax. A supplementary question "Are the bits moving in the solid wax?" resulted in a range of responses from the 30 students who had at least some ideas about a particulate nature for the wax:

| | |
|---|---|
| No movement at all | 18 students (2 x S4, 1 x F2, 4 x F3, 1 x F4, 2 x F5, 2 x F6, 4 x F7, 2 x T) |
| They would move now and then | 2 students (2 x F3) |
| Continual slight movement | 3 students (1 x F4, 1 x F5, 1 x F6) |
| Continual vibrational movement | 7 students (2 x F3, 1 x F4, 2 x F6, 2 x F7) |

With regard to the molten wax, there was a general appreciation by students that there would be increased movement by the particles. Rapid particle movement was envisaged by 9 students (1 x F1, 1 x F3, 5 x F6, 1 x F7, 1 x T) and this movement was generally associated with heat. Some older students had grasped the 'scientists' model quite firmly:

> "Like Brownian motion ... the particles are colliding with each other". (603, 703)[4]

> "When it's melting, it's breaking inter-molecular bonds and they are becoming free from the crystal structure". (702, 704)

On the other hand, there were those who envisaged that the particles would be 'moving slowly' (1 x F7, 1 x T) while some only associated the movement with the bulk movement of the molten wax.

> "Yes, (they would be moving) because the drops that come down ... make more splash about ... and more movement". (501)

> "Not really, unless you bumped it ... it might shake to one side". (304)

(b) The flame

The question: "What bits are in there in the flame?" produced a broad range of answers.

i) Twenty students, of all ages (2 x S4, 1 x F1, 5 x F2, 4 x F3, 2 x F4, 2 x F5, 3 x F7, 1 x T) envisaged no particles in this region.

Some of these students saw the flame as being made up of successively smaller flames.

> "It would be like a miniature size of the big flame". (303)

> "A whole lot of little ones ... moving up and down like a big flame". (304)

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[4] In this paper Std 4 students are identified with a three digit number beginning with 0, e.g. 002; Form 1 with a 1, e.g. 102; and so on. Teachers college students are identified with an 8.

"The flame would be made up of little flames". (401)

ii) Twenty-one students (1 x S4, 3 x F3, 7 x F4, 3 x F5, 3 x F6, 3 x F7, 1 x T) also considered that particles might be found in the flame. There were a number of descriptions of what these particles would be and of their possible origin.

"Burnt little bits drop off". (402)

"Pretty small bacteria". (203)

"Oxygen from the air". (302)

"I suppose it would be oxygen particles with the wick and as that burned it would go off into the atmosphere". (401)

"The match ... they (particles) must have started from the match somewhere". (501)

"hydrogen particles ... from the air". (802)

The idea of a hydrocarbon gas being in the flame was offered by 2 students (2 x F7).

iii) In summary, the flame was a mystery to many students and even a number of senior students were not sure if there would be particles in the flame. The views of four of these senior students with respect to the solid wax, molten wax and the flame are given below.

| STUDENT | SOLID WAX | MOLTEN WAX | FLAME |
|---|---|---|---|
| 704 | particles - no movement | particles - movement because bonds break | "Don't know" |
| 705 | atoms - no movement | atoms - moving | "Don't know" |
| 706 | molecules - no movement | molecules - moving faster | "not made up of atoms or molecules or anything" |
| 801 | particles - stationary | particles - moving slowly | "I don't think there are any particles in there" |

EVENT 2: NEUTRALIZING

An acid solution and an alkaline solution[5] were presented to the students who were then invited to place similar volumes in separate test tubes. A container of universal indicator was nearby. After some initial discussion focussing on whether or not they considered the liquids to be made up of particles the students were asked to place a few drops on universal indicator into the acid. After exploring this situation, the alkaline solution was added to the acid.[6] Questions were structured so that students had the opportunity to predict what would happen at each stage, giving their own explanations for any observations. In the following discussion only some of the unique features of this event, and the associated discussion, will be reported.

(a) "There has been a reaction".

Thirty-two students (3 x S4, 1 x F1, 3 x F2, 4 x F3, 6 x F4, 4 x F5, 3 x F6, 6 x F7, 2 x T) appreciated that there had been some interaction between the two solutions although the nature of this interaction appeared to be well understood, from a scientific viewpoint, by only 2 of the more experienced students (2 x F7). Even some of the older students (2 x F6, 3 x F7, 1 x T) who tended to use the term 'reaction' could give no explanation beyond this, i.e. they appeared unable to provide a mechanistic model of what might be happening. One or two students expected a 'reaction' but in their view one didn't take place. For example,

A "They should react but there doesn't seem to be anything formed on the bottom".

I "What were you expecting?"

A "A precipitate". (603)

Other senior students used the term neutralizing (1 x F4, 1 x F6, 4 x F7) although the term wasn't always clearly understood in a scientific sense. For example, one students asked to explain what he meant when he talked of neutralizing stated,

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[5] Equi-molar solutions of hydrochloric acid and sodium hydroxide.

[6] The interviewer ensured that an excess of alkali was provided.

"The alkali cancels out the acid". (602)

and was unable to elaborate further.

A detailed understanding of the reaction mechanism was looked for in the more experienced students. The structure of sodium hydroxide and hydrochloric acid, in terms of other particles, was explained by 8 students (2 x F6, 4 x F7, 2 x T) with 4 (1 x F6, 3 x F7) pointing out the presence of ions in the acid solutions; and 4 (4 x F7) mentioning ions in the sodium hydroxide solution. However, the presence of ions in the hydrochloric acid was not realized by some of the more experienced students:

"HCl molecules just floating around". (702)

9 students (2 x F6, 6 x F7, 1 x T) predicted the formation of new products in this reaction and, of these, 8 students (1 x F6, 6 x F7, 1 x T) were able to identify water and sodium chloride as reaction products.

(b) "Things change colour"

Many students were much happier talking about colour changes.[7] This involved concrete ideas and didn't involve talking about abstract particle behaviour. A third form girl provided a good example of this,

I "I wonder what will happen if I pour that sodium hydroxide into there (solution of acid + indicator).

V "It will go a bit lighter". (303)

Older students occasionally considered things simply in terms of colour changes, as the following comparisons show:

"I don't know - they just change colour". (301)

"They just change their colour when they mix together". (304)

"When the two things got together, it's like mixing paints - you mix two colours to get another colour". (402)

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[7] The prediction of red colouration, when the indicator was added to the hydrochloride acid, was correctly made by 11 students (3 x F4, 2 x F6, 6 x F7) and the prediction of a change to blue, via the addition of excess sodium hydroxide solution, was made by 9 students (3 x F4, 2 x F6, 4 x F7).

"The two colours mix and you get a different colour". (404)

"Well, they've mixed together so the colour's changed". (502)

"(Why the colour change?) Mixing the two colours". (802)

(c) "It will probably fizz up or explode"

We have found in other studies that young children in particular associate chemistry, or even science, very much with bangs and explosions. This view was clearly stated by a Form 4 student:

I "I'm going to take this acid and add it to this solution of sodium hydroxide here. Any idea what is likely to happen?"

B "I don't know - it might explode ... sometimes when you put two chemicals together, they react a bit violently".

I "Have you seen that in the laboratory, chemicals being mixed and reacting violently?

B "Not really - I've just been told". (401)

It is not surprising therefore that younger students when asked to predict what would happen when the acid and alkali mixed suggested explosions or at least something dramatic. For example a Form 2 student predicted "it will fizz up" while a fourth former told us,

"When you add two substances like those two (points to acid and alkali) it would probably form a new substance or cause an explosion". (403)

EVENT 3: PRECIPITATION

Students were shown samples of solid sodium chloride and lead nitrate, which were then dissolved separately in water. The resulting solutions were later mixed together to form a precipitate of lead chloride.

Discussion was directed towards the individual solids, the two solutions and the precipitate, in terms of particle behaviour.

The following analysis of responses highlights some of the more typical ideas that students offered concerning solids, solutions and precipitation.

(a) "I don't think solids have particles"

Although 11 students (2 x S4, 3 x F2, 2 x F3, 3 x F4, 1 x F5) felt that the lead nitrate was not made up of particles, only six students (2 x S4,

2 x F2, 2 x F4) were definite in their opinions that there were no particles in solid sodium chloride.[8]

This notion that not all substances are made up of particles was well established with some students.

"Because that's a solid and I don't think solids have particles". (001)

also,

I "Do you think there are particles in everything?"

P "I don't think so".

I "What sort of things wouldn't be made up of particles?"

P "A box (points to a cardboard box).

I "There are no particles in there?"

P "No - I don't think so". (301)

Similarly, a student who had previously stated that he considered there were particles in solid wax, molten wax and even steel, was asked,

I "Is everything made up of particles?"

W "No".

I "What sort of things do you think are not made up of particles?"

W "Leather".

Pupils were able to rationalize their ideas.

I "Why do you say leather - tell me about that".

W "It's animal skin and if it were all particles it would split or something". (302)

(b) "When solids go into the water"

When the dissolving of the compounds in water was discussed 12 students (1 x S4, 1 x F1, 3 x F2, 1 x F3, 4 x F4, 2 x F5) did not refer to the term dissolving. Some of these referred to melting.[9] For example,

"(What's happened to the solid) it's just all melted away". (403)

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[8] This marginal increase of pupils thinking that lead nitrate did not contain particles was largely unexplained. The elements within the two solids were indentified by 7 of the older students (2 x F6, 4 x F7, 1 x T), although the idea of ions in the solids was rarely proposed (2 x F7).

[9] See also the Working Paper on 'Physical Change'.

Others who did use the word dissolve, really had similar views to this,

I "What do you mean by this word dissolved?"
A "Something that's melted away". (401)

or displayed other interesting viewpoints,

I "What do you mean by dissolving?"
A "It's becoming saturated with the liquid until it can't hold any more". (406)

A variety of views were held about what happened to the particles in the compounds.

i) 'the particles disappear' (1 x S4, 1 x F3)
"(they are not there now?) No ... they've disappeared" (301)

ii) 'the particles decrease in size' (1 x F3, 1 x F4, 1 x F5)

I "What do you mean by dissolved?"
M "Sort of gone into the water".
I "Are the particles still in this test tube?"
M "Yes".
I "But I can't see them - why not?"
M "They will have gone smaller in the water".
I "Do you think the actual particles have gone smaller?"
M "Yes".
I "They have actually shrunk with the water?"
M "Yes". (306)

iii) 'the particles actually change from solid to liquid particles' (1 x F4, 1 x F5)

I "Are the particles still there?"
K "Yes, but they have changed their form".
I "How have they changed?"
K "From a solid to a liquid". (501)

In the above cases it is difficult to decide whether students were using the word 'particle' in an everyday sense of a grain, or whether they considered that 'molecules' undergo these changes. In either case the students are likely to have problems with ideas involving the use of the word particle.

(c) "It's all gone murky"

Asked what they considered had happened when the two clear liquids were mixed together and a white precipitate formed, only 5 students (1 x F6, 4 x F7) used the word 'precipitate' in their response. Many students were happy simply to describe what they saw happening.

"The two solids have made the water murky". (401)

"Real murky water". (306)

"It's gone murky". (707, 802)

"Milky". (801)

Others used more scientific words but didn't add any further informatiom.

"It's gone into a milky solvent". (303)

"The two formulas mixed in and the water in there may be a kind of coloured liquid". (406)

"A white fluid". (702)

Through questioning students about the precipitation it was possible to determine in almost all cases whether or not the student envisaged an interaction between particles during the reaction.

i) 'A new substance has formed'

The precipitate was seen to be a new substance (which was neither lead nitrate nor sodium chloride) by 10 students (1 x S4, 1 x F2, 3 x F4, 1 x F5, 1 x F6, 3 x F7). Of these students the precipitate was correctly identified by 4 people (1 x F6, 3 x F7) although a scientists' view of the mechanism behind precipitation was expressed by only one student (1 x F7).

ii) 'The substances have settled out as some sort of composite mixture of the two'

Ten students (2 x S4, 4 x F2, 1 x F3, 1 x F4, 2 x F5) thought that the sodium chloride and lead nitrate simply joined together in some way and settled out without forming any new products.

"The particles joined up again and they went straight to the bottom and just stuck there". (402)

"They just joined together again". (501)

iii) 'The substances have just settled out'

Eleven students (1 x S4, 1 x F1, 5 x F3, 2 x F4, 1 x F5, 1 x T) felt that the sodium chloride and lead nitrate settled out without interacting in any way.

"The heavy solids sunk to the bottom". (101)

"Well, the particles seemed to be undissolving again or coming back together". (501)

iv) 'Something's settled out'

The remaining 10 students (1 x F2, 1 x F3, 1 x F4, 1 x F6, 6 x F7) tended to view the precipitate as consisting of only one solid but they were unsure what the precipitate was or how it was produced.

"Some of the particles that haven't reacted". (801)

"I think the nitrate part has dissolved. I can see the lead doesn't completely dissolve". (802)

In summary about 50% of students did not envisage a reaction of any sort and, to some older students, it was quite clear that no reaction had occurred. For example,

"If those two (sodium chloride and lead nitrate) had reacted, it would have gone clear". (705)

EVENT 4: 'EXPLOSIVE' OXIDATION OF MAGNESIUM

This event dealt with the rapid oxidation of magnesium. A finely divided mixture of magnesium and potassium permanganate was placed on a piece of card and heat supplied. This was achieved by means of a piece of high resistance wire, connected by a length of cable, to a power pack.

When the switch was turned on, the reaction was witnessed in the form of a cloud of white smoke. Students were given the opportunity to see the solid mixture being produced initially, followed by the insertion of the high resistance wire.

Prior to the reaction, students were asked not to look directly at the mixture but to focus their attention about 20 centimetres to one side, so they were not temporarily blinded by the flash.

Questioning was directed toward finding out whether or not, and in what way, students considered the reaction to involve particles and particle behaviour. Various descriptions of the reaction followed.

"There was a big flame and smoke". (401)

"It's just blew". (402)

"The heat did something to the powders - they just exploded like - into a big puff". (305)

Eight of the younger students (1 x S4, 1 x F1, 3 x F2, 1 x F3, 2 x F4) felt that the original mixture was not made up of particles and a number of other isolated conceptions were brought out during the interview.

i) 'Particles have become shattered'

Twelve students (2 x S4, 1 x F2, 5 x F3, 3 x F4, 1 x F5) considered that some of the actual particles would have been shattered after the reaction.

V "They'd (particles) just kinda explode - kind of shatter".

I "Do the little bits sort of break up? When you say shatter, do you mean break up?"

V "Yes".

I "And what's the smallest bit that's left then?"

V "Little shattered bits".

also,

I "What about when things are heated?"

A "They (particles) are burnt up". (305)

Some older students also held this view:

"The molecules got too hot and just exploded". (504)

ii) 'Particles can disappear'

Eleven students (1 x F1, 1 x F2, 5 x F3, 1 x F4, 3 x F5) felt that all, or some, of the particles disappeared after the explosion.

I "When you say 'lost', do you think they would disappear?"

V "Yes".

I "Even if they were sealed up (in a closed container)?"

V "Yes".

I "So they have gone all together?"

V "Yes".

I "Would it (the container holding the reaction) weigh more or less afterwards?"

V "Less".

A similar viewpoint from an older student:

D "It would weigh less".

I "Now why do you think that? - tell me about that".

D "Because when it was ignited some of them (particles) would no longer be there". (505)

iii) 'Particles expand on heating'

I "You say the things in here are expanding. What do you mean by that?"

C "The molecules".

I "The molecules are expanding ... how are these molecules behaving?"

C "They're getting larger". (408)

also,

"Probably all the molecules have expanded furiously". (408)

iv) 'Particles catch fire when heated'

I "That cloud of smoke that you saw ... what is the cloud of smoke?"

J "Just the particles burnt up ... caught alight and then floated away". (404)

The same student reinforced his stance on 'burning particles' - combining this idea with 'exploding particles':

"Well, they (particles) just heated up, caught alight and exploded". (404)

This idea was found amongst some older students:

I "... and what do you think happened to these particles?"

D "When the heat was put on them it sort of lit them all up".

I "How do you mean? Tell me more about that".

D "When the heat was put on them it made them react and sort of ignited them".

I "... these particles caught fire?"

D "Yes". (505)

v) 'Particles can expand or change shape or colour'

I "What do you think happens?"

C "It might do something to the particles".

I "What sort of thing?"

C "They might expand or change shape".

I "Anything else?"

C "I suppose they could change colour". (408)

vi) 'Particles melt or shrink'

"We have the explosion and from the heat they would (particles) sort of melt and melt together again". (401)

The original solids were seen by 16 students (2 x F3, 3 x F4, 2 x F5, 2 x F6, 5 x F7, 2 x T) to be converted completely into gaseous products.

"It would've formed a gas and blown away with the wind". (302)

also,

S "I suppose they disappeared into the atmosphere".

I "As what? Have they changed at all or have they just disappeared...?"

S "They probably ... some sort of gas". (704)

Some younger students reverted to the 'shrinking particle' model in order to explain the production of smoke:

I "What's happened to the particles?"

K "They've just kind of formed smaller particles". (401)

vii) 'Particles and weight'

Opportunity was provided for students to express their views on conservation of mass by discussion of a hypothetical case, whereby such a reaction was performed inside a closed container, which was weighed before and after the reaction was initiated.

Six students (2 x F3, 1 x F4, 3 x F7) had firmly grasped the idea of conservation of matter with good responses coming from some younger students.

I "If we could do that little experiment inside a closed container and not let anything escape - and weigh the solid beforehand, throw the switch and weigh everything that came off. Do you think there would be any change in weight?

J "I don't think so".

I "How would that be?"

J "Because all the particles are still there".

I "So if all the particles are in there - does it matter whether there is a solid or a gas - whatever - if all the particles are there, they would still weigh the same - you think?"

J "Yes". (306)

None of the students felt that the products from the reaction might have weighed more than the reactants.

Twelve students (6 x F3, 2 x F4, 1 x F5, 1 x F7, 2 x T) were convinced that the reaction products would weigh less than the reactants.

A number of explanations were offered.

I "Tell me about that - why would it get lighter?"

A "Because they would be floating around in the container - they wouldn't weigh anything because they would be floating around in the container". (305)

A "I think it (reaction products) would be lighter".

I "Why would that be?"

A "We did a weight experiment yesterday and once a solid was changed to a liquid the weight became lighter. I suppose that changing the state changes the weight". (405)

"It's less dense though ... I think it (reaction products) would be lighter because they would be moving around". (801)

I "Tell me about that change. Would they (reaction products) weigh more or less?"

C "It would weigh less after the explosion and the reason would be that gases are less and it's all to do with gravity". (802)

Further discussion about particles and things

At the end of the 'interview-about-events' session, a number of cards were produced so that the students might consider the particular word that was printed on each card. These words were: particle, atom, and molecule. Each term was discussed with the student in order that some further insight into the meaning of these words might be obtained. It must be remembered that the discussion took place against the background context of the four events just considered.

(a) Particles

Only 2 pupils (2 x S4) said that they had not heard of the term particle. However students had a wide variety of meanings for the word with 8 students holding the scientific view of particle as a 'collective' or general term to describe atoms, molecules and so on. (2 x F3, 1 x F4, 2 x F6, 3 x F7).

"I think 'particles' is just a family name for those (atom, molecule)". (602)

"Perhaps a simplifying term which encompases atoms, molecules, and that sort of thing". (701)

The following exemplify some of the other comments made about particles which did not emerge in the discussion relating to the four events.

i) 'Everything is made of particles?'

Twenty-one students (1 x F2, 4 x F3, 3 x F4, 3 x F5, 3 x F6, 5 x F7, 2 x T) felt that particles were present in all matter.

I "What's a particle? What does that mean to you?"

J "A part of a solid or a gas or a liquid".

I "So everything is made up of particles".

J "Yes, I think so". (306)

There were other widespread views concerning the location of particles, with 18 students (1 x S4, 1 x F1, 4 x F2, 3 x F3, 6 x F4, 2 x F5, 1 x F7) suggesting that particles are found only in certain kinds of substances.

I "What sort of things generally are made up of particles?"

V "Hard sorts of things".

I "All solids".

V "No - not all of them - when you are doing experiments - salts and crystals and all that.

I "What solids aren't made up of particles - do you think?"

V "Natural stuff like coal, dirt and clay".

I "Are all liquids made up of particles?"

V "No - just some".

I "What liquids wouldn't have particles?"

V "Soft drinks".

I "... what about a bottle of milk?"

V "No".

I "Why aren't there particles in milk?"

V "Because the milk comes from animals".

I "I see - so if I had a leather briefcase - would that be made up of particles?"

V "No". (303)

ii) 'More science means more confusion about particles'

Particle is a word with no clearly defined meaning in science. Hence it is perhaps not surprising that even senior students can be confused.

I "'Particle' - what does that word mean to you?"

D "A thing made up of molecules". (505)

"I use the word particle but I don't know what it means really". (603)

"A particle is made up of atoms". (601)

I "'Particle' - what's a particle?"

L "It's a thing made up of two or more of the same kind of atom"

I "... can we talk about particles in steel?"

L "I don't know". (705)

I "You mentioned solids - can you have particles in everything - or what?"

K "No - I suppose just in solids". (703)

(b) Atoms

The term 'atom' appeared to cause a good deal of confusion and only 1 student (1 x F6) seemed to have a clear scientific understanding of the term.

Only 12 students (2 x F4, 1 x F5, 3 x F6, 6 x F7) thought that all matter was made up of atoms,

I "What sort of things have atoms in them?"

J "Liquids have atoms in them".

I "What about solids - any atoms in solids?"

J "No". (403)

i) 'An atom is an ant, an insect or an exploding bug!'.

One or two younger students had interesting ideas about atoms.

I "What do you think we mean by the term 'atom'?"

R "I've heard of Atom Ant. I've heard of a little atom".

I "What is a little atom".

R "I think it's an insect". (402)

I "What's so different about an atom then?"

A "Well, it's a little bug that floats around - it can explode".

I "... why are you so sure there are atoms in the air? How does that tie in with the exploding?"

A "When the atom bomb explodes - it explodes in the air". (305)

Some of the older students introduced 'scientific' words into the conversation but whether, or not, they understood the scientific meanings for these words is open to debate.

"If things have a nucleus, then it has rings around with more atoms in each ring - sort of". (405)

"Atoms are in substances with a nucleus". (406)

ii) 'Atoms and electricity'

There seem to be an association in a few student minds between atoms and electricity.

I "Can you think of anything that could have atoms in it?"

V "Things to do with electricity".

I "What sort of things - wires - are they to do with electricity?"

V "Yes".

I "Are there atoms in the wire - do you think?"

V "Yes - I think there might be". (303)

I "What about that word - atom?"

W "Very small - you can't see it unless it's under a big microscope, and it contains power".

I "What's the difference be ween an atom and a particle?"

W "A particle doesn't contain power and an atom does".

I "... are there atoms in all materials?"

W "No".

I "What sort of things wouldn't have atoms?"

W "Those bricks (points to the wall) and concrete".

I "Are there particles in the bricks".

W "Yes".

I "Why is it that atoms aren't in bricks - do you think?"

W "Because bricks don't have power".

I "Where would you find atoms then?"

W "In wires - tins - metals".

I "All metals have atoms?"

W "Yes".

I "What about wood."

W "No". (302)

(c) Molecules

Only 7 students (1 x F6, 6 x F7) seemed to understand the term 'molecule' and to be able to view it as a specific type of particle.

i) The term 'molecule' was frequently used without any meaning.

I "What about 'molecule' - what does that mean to you?"

M "We are just doing that in science - the last project. Something to do with adhesion - cohesion. (307)

I "What about that word - 'molecule' - what's a molecule?"

P "Several atoms - or particles - joined together". (405)

"It's (a molecule) a small little bubble thing". (504)

I "How do you see molecules?"

R "Tiny little objects all joined together".

I "Do they have any particular shape?"

R "Just a round circle". (602)

ii) Discussion of the terms 'particle' and 'molecule' led to much confusion when viewed from a scientific perspective.

"Particles are hard and molecules are sort of liquid". (304)

"Particles are parts of structures. I think molecules are part of those particles". (406)

"Molecules are several particles". (405)

"Molecules make up a particle". (505)

I "Particle and molecule - can they be the same or are they quite different?"

R "I think they would be different". (602)

"If I had particles joined together, that would form a molecule". (601)

I "What about 'particle' and 'molecule' - any relationship - or not?"

T "All particles make up molecules". (604)

I "Would you be happy to say that a molecule is a particle?"

L "No - I don't think so".

I "A molecule is not a particle?"

L "No". (705)

"All atoms are molecules". (406)

I "What about the difference between a molecule and a particle?"

B "I think a molecule is just smaller".

I "What about a molecule and an atom? Are they the same?"

B "The molecules are smaller than the atoms". (402)

I "'Atom' and 'molecule' - any relationship there? Any similarities?"

C "I know one time you are supposed to use atoms and another you are supposed to use molecules, depending on what happened". (802)

"A molecule is made up of two particles". (802)

SUMMARY

During the exploratory phase of the Learning in Science Project many teachers expressed concern over problems associated with teaching certain basic ideas in chemistry at the Form 1-4 level. For example,

"Fourth form kids may be able to talk about atoms or bits of atoms but when it comes down to it they can't really relate that to how things are behaving". (Head of Junior Science)

"The simple things like what an acid is? What a base is? But even that was not getting through". (Head of Science)

"The test tube is real and it smells, but when we teachers ask pupils to take the smell and think about it in terms of atoms being rearranged and molecules whizzing around, then you have got a bit of a problem". (Head of Science)

We believe this in-depth investigation supports these comments. In our view a significant percentage of students:

(a) Do not appreciate the basic particulate structure of all matter

(b) Are confused by the word 'particle' with its multiple meanings and do not understand the word 'atom' or 'molecule' in a scientific sense.

(c) Do not consider that weight, or even particles, are necessarily conserved in chemical reactions.

(d) Identify the more dramatic events, e.g. exploding, with chemical reactions while less dramatic reaction, e.g. neutralizing and precipitation, are not identified as chemical reactions at all.

(e) Prefer to talk about what is observable, e.g. colour changes, rather than talk about an abstract molecular model of what might be happening in a chemical reaction.

Chemistry appears to be a complex subject to many pupils and the behaviour of invisible particles is often difficult to portray. Yet to us, as teachers, there is an underlying simplicity in that atoms are neither created nor destroyed but simply rearranged in a chemical reaction. Are simple molecular model ideas beyond the level of abstraction of the majority of pupils? Can certain experimental work and diagrammatic representations be found which have particular impact on students' thinking? Does the use of the word 'particle' introduce more confusion rather than less? We would be interested in your views.

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## APPENDIX: ASPECTS OF CHILDREN'S SCIENCE

As we said earlier this investigation, more than any other in the series, explored children's views about scientific phenomena and languages. Nevertheless, examples of children's science, were detected and some of these can be found in the body of the paper. Here some additional examples are provided.

### Everyday language

The word 'indicator' was used in the everyday sense by one or two younger children,

"a thing that sticks out of cars". (305)

The word 'acid' also has something of an everyday meaning,

"some acids are in bombs and things like that". (401)

"something harsh that can burn, like in a James Bond movie". (307)

### Human-centred viewpoint

To try to gain some indication of how students envisaged the wax in the candle students were asked "if we could get down into the structure of the tiniest bit of wax, what would we see." While most responses indicated an appreciation of what the interviewer was trying to investigate - a rather analytical consideration of the wax - some younger students interpreted the question from a much more human-centred perspective.

"The wax ... it would cling to you". (101)

"You couldn't see much ... it would be all blurry ... it's just all around you". (305)

"Cold, not having any room to move". (410)

Another example, of the human-centred viewpoint is provided by a sixth former asked whether or not there were particles in the flame of the candle.

"There must be something there because you can see the flame and you can feel it if you put your hand there". (603)

Attributing human characteristics to inanimate objects

Scientists, in attempting to communicate ideas to others, often use this type of metaphor. When a third former uses such ideas one is unsure just how literal their viewpoints actually are. Here a third former considers what happens when indicator solution is added to an acid.

A "They've got them all excited like, and got them to go red".

I "Because they've been sort of excited?"

A "Yes". (305)

Also,

"They (particles in a solution) are just swimming around like they are drowning". (305)

Event 4, the explosion led to a number of these viewpoints.

I "What has happened to those particles?"

G "Burned and shrivelled up".

I "Is there anything left?"

G "Probably just dead lumps".

I "The particles are actually dead - finished?"

G "Yes".

I "Were they living before?"

G "Yes". (201)

Also,

I "How do you think the atoms ( the pupil's word) behaved when they were heated by that wire?"

J "Took a fit and jumped in the air". (203)

The interviewer's use of the word 'behaved' was usually guarded against since it might suggest 'animal behaviour', to the young students. However, refocussing on this point revealed that the student had firmly grasped an animistic view of particle behaviour.

I "I wonder what happened to the atoms (the pupil's word) there?"

J "They're scrapping it out ... hurting each other". (203)